Monthly Technical Progress Report No. 33 March 15, 1967

February 10, 1967 to March 1, 1967

POLYMERS FOR SPACECRAFT HARDWARE

Prepared for:

Jet Propulsion Laboratory
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Pasadena, California 91103

Contract No. 950745

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SRI Project ASD-5046

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Copy No. 19

SCOPE

This report covers work performed during the period February 10, 1967 to March 1, 1967 on "Polymers for Spacecraft Hardware," SRI Project No. ASD-5046 under JPL Contract No. 950745.

The primary objectives of this program are to assist the Jet Propulsion Laboratory of the California Institute of Technology in the examination of polymeric materials to be used in connection with JPL spacecrafts, and to prove a study of the effects of simulated spacecraft environments on selected commercial polymeric products. The materials to be studied have been provided by the JPL Cognizant Engineer.

WORK PERFORMED

Volatile Condensable Material

Volatile condensable material (VCM) is defined as the weight of condensate obtainable at 25° C in a given interval of time from a unit weight of a thin sample of material maintained at 125° C in a vacuum of at least 5×10^{-6} torr. The micro-VCM technique has been established as a procedure for rapid screening of polymeric samples of the order of 100 milligrams for maximum-VCM content and total-weight-loss. The limits of acceptance for further evaluation of polymeric products have been established as <1% weight-loss and <0.1% VCM, as obtained in the micro-VCM procedure.

The macro-VCM technique, utilizing samples of 3 to 10 grams, provides information on the deposition and re-evaporation of VCM as a function of time, as well as weight-loss data; it is used for materials which qualify for further evaluation as a result of micro-VCM determinations, as well as for materials which have marginal qualifications but are unique and critical for spacecraft applications.

Micro-VCM

Micro-VCM data for several film-type adhesives are summarized in Table 1. These materials were considered to be of sufficiently good characteristics to be evaluated further, and are included in the current comprehensive polymer test program (vide infra).

In Table 2 are micro-VCM data for a number of sleeving materials, which illustrate the effects of different curing cycles. The results obtained after cures of 24 hr/150° C, requested by the Cognizant Engineer, were reported in Interim Report No. 3; the determinations have been repeated on the materials in the as-received state since current practice at JPL is to use them directly without postcuring. It is interesting to note that the material recommended as a suitable candidate for spacecraft use after the cure at 150° C for 24 hours is also the most suitable candidate in the as-received state.

In the search for windows for the far infrared region, space-experiment designers have considered use of high-melting-point waxes (75-80° C) which show good transparency in the normal infrared region as thin films. In view of the fact that these materials are far away from heat sources or other critical optical components, micro-VCM determinations have been made at a moderate temperature of 70° C. These results are summarized in Table 3.

Micro-VCM by IR

Additional work has been performed on the application of an infrared spectrophotometric technique for VCM as a measure of quality control. As shown in Table 4, the wt-% of VCM collected on optical salt flats is within experimental error for VCM content as weighed on the copper discs (see also Monthly Report No. 32).

Preliminary measurements (see Table 5) for VCM from sleeving materials releasing the same type of silicone ("A") and for VCM from a coating material and an elastomer releasing another type of silicone ("B") indicate that a nearly-quantitative relationship may be established between absorbance and weight of VCM. As shown in Figure 1, the curves for different types of basic polymers are different, and thus calibration must be made for individual polymeric products.

Fabrication of modified retaining rings for the salt flats, (to prevent the loss of salt in handling and ensure more accurate weights) is nearly complete. Additionally, it appears feasible to use standard salt flats of about 1/4" thickness rather than the more fragile 1/16" thick flats used

in original experiments; modified holders are being fabricated. As soon as these new design features are incorporated, work will be initiated on the preparation of reference IR spectra for VCM from commercial polymeric products which are suitable for spacecraft use, and also on the correlation of infrared absorbance with weight of VCM.

Macro-VCM

Macro-VCM determinations have been completed for 3M's Velvet Black 101-C10 and Borden's Mystik Tape 7452. As shown in Table 6 and Figure 2, the acceptable level of VCM from Mystik 7452 is in agreement with that obtained in micro-VCM determinations (0.04%, Interim Report No. 3) and evidence is that it may disappear with time. Further evaluation of this tape includes examination of mechanical performance in a thermal-vacuum environment and identification of volatilized substances (vide infra).

There are also indications that the VCM from Velvet Black 101-C10 (Table 6) may disappear with time (Figure 2). A brief study of the effects of curing time at moderate temperatures of 25° C and 110° C (Monthly Report No. 30) indicated that the 168-hr period at 110° C was most appropriate and thus was used for this determination. (See "Identifications" for analysis of VCM.)

Macro-VCM determinations are in progress for Luvican M170, Delrin NC-10, Eccofoams S and FS, and Electrofilms 2396 and 4306.

Identification of Volatilized Substances

The substances volatilized from samples of Mystik 7452 and Velvet Black 101-C10 at 125°C and 10^{-6} torr were examined in situ by mass spectroscopy. As summarized in Table 7, the primary components of VCM for both of these materials were identified as low-vapor-pressure plasticizers (or fragments of base materials) such as esters of phthalic acid, sebacic acid, and benzoic acid. The products were used in the same fashion as that for the macro-VCM determinations, i. e., Mystik 7452 - as received, and Velvet Black 101-C10 - cured 168 hr at 110° C.

In connection with another program sponsored by JPL at SRI, the Cognizant Engineer requested that determination be made of the presence

and identification of any substances which might volatilize at 125° C in vacuo from proposed lubricant coatings. The samples were coatings of WS_2 and WSe_2 on steel (Dicronite Lubricants, Division of MPB, Inc.). Each sample was placed in a container directly attached to a medium resolution mass spectrometer of high sensitivity and evacuated by ion pumping at room temperature to a pressure of 1×10^{-7} torr. A low background was recorded, and then the sample was raised quickly to a temperature of 125° C and the spectrum was recorded. For each sample, no change in pressure was noted on the ionization gage, and no spectrum above background was recorded except for the barest trace of common hydrocarbons.

Comprehensive Polymer Test Program

The comprehensive polymer test program is designed to determine changes which have occurred in pertinent properties of polymeric materials after a decontamination treatment, a thermal-vacuum exposure, and a decontamination treatment followed by a thermal-vacuum exposure.

The comprehensive test program (Series II) has been completed for the 30 polymeric products listed in Table 8. The equipment, operations, and procedures for the test program are described in Interim Report No. 3. Additional test procedures or sample preparations used for this batch of materials (Series II) are described below:

(1) Dielectric Constant and Dissipation Factor

Specimens of protective coating material were first cured in flat sheet 1/16" thick and then die-cut to 2.000" diameter. Specimens of sealant material were cast in aluminum molds 2.000" in diameter and 1/8" thick. The micrometer electrode system (G-R, Type 1690A) was used for these samples.

(2) Compression Set

Compression set measurements were made in accordance with ASTM D-395.

Aluminum molds were fabricated for casting and curing samples for compression-set measurements. The compression-set test-blocks were designed and fabricated to

fit the sample cells; the flat plates of the test-blocks were made from stainless steel 304 and the bolts and spacers from Invar. Taking into account the relative thermal expansion coefficients between Invar and stainless steel 304 (0.8×10^{-6} vs 9.6×10^{-6}), there should be little if any detectable change of the initial compression pressure.

(3) Compressive Strength

Compressive strength measurements were made according to ASTM D-1621; the rate of compression was 0.1 in/min.

Test specimens of foam material were cut with a rotating die which had a diameter of 2.250". Sealant material was cast in 2.250"-diameter molds at a thickness of 1.000 in.

(4) Adhesion Shear

Aluminum strips 1" x 4" x 1/16" with a hole drilled 1/4" from one end were prepared from grade 2024-T3 (unclad) aluminum. The strips were cleaned by sandblasting, degreased with acetone, and then immersed in an aqueous solution of Altrex (6-8 oz/gal) at about 80° C for 8-12 minutes. They were then rinsed with de-ionized water and oven-dried at 70° C. All applications of adhesive or protective coatings to the test strips were made within 8 hours of the cleaning process.

The adhesives and protective coatings to be tested were applied to a ruled area measuring 1.0" x 0.5" at the end each aluminum strip, opposite the hole (used for suspending test specimens in the various environments). The strips were then mated and a load of 25 psi was applied in most instances and the samples were cured as shown in Table 8.

Control and exposed specimens were pulled with a crosshead speed of 0.05"/min, using an Instron Model TTCLM-6. The temperature of the test specimens was 70° F during all testing.

(5) Tensile and Elongation

Tensile specimens of seal and gasket material were cut from 6" x 6" x 1/16" cured stock by an ASTM die C.

Test specimens of lacing tape were cut 8" long from the spools and used as-received.

(6) T-Peel Test

T-peel test specimens were prepared from 23"-lengths of tape and thermal insulation material. They were folded in such a manner as to bring the adhesive-coated sides of the tape in contact with each other and give 6" of test area in which to measure the peel resistance (see Figure 3). After folding the specimens, they were rolled with a 1/2-in diameter roller.

The tab ends (Figure 3) of the test specimens were clamped in the grips of the tension testing machine and pulled with a crosshead speed of 1.00 in/min.

Note: This crosshead speed will cause separation of the bond area at a rate of 0.50 in/min.

From the load curves, recorded on the Instron, the average peeling load for the first 5 inches of peeling after the initial peak was determined and reported in lb/in of width. All measurements were made at 70° F.

Adhesives (Tables 9-11). - A consistent loss in adhesion shear of about 20% is noted for RTV-40/T-12 after any of the treatments. The other adhesives show a decrease in adhesion shear of -7 to -45% after the ETO treatment, but an acceptable recovery of values from -5 to +25% vs control after the following thermal-vacuum treatment; exposed to the thermal-vacuum environment only, they indicate acceptable differences from the adhesion shear of control samples of -8 to +25%.

Foam Material (Tables 12-14). - Little change (i. e., less than ± 20%) is incurred for dimensions or compressive strength by Eccofoam SH subsequent to any of the exposures in the test program. However, there is a noticeable difference in compression set.

Protective Coatings (Tables 15-17). - The protective coatings incur gain in weight, loss in adhesion strength (>20%), and little change in electrical properties (except for Stycast 2741 and Stycast 1269) after the ETO cycles. After a thermal-vacuum exposure only, weight losses are incurred but adhesion shear is improved (over control) and electrical properties remain about the same (except for Stycasts 1269 and 2741). The effect of exposure to both environments indicates again weight losses but a general increase in adhesion shear (over control) and little difference in electrical properties except for the two Stycasts. Although

Stycast 2741 appears to have improved adhesive strength after the thermal-vacuum environment exposure, samples which were exposed completely (in contrast with those exposed only at the periphery of sandwiched plates for the adhesion tests) were so degraded that final measurements of dimensions, weight loss, or electrical properties could not be made.

Sealants (Tables 18-20). - The most noticeable changes in mechanical properties following ETO teatment are incurred by RTV-602. It shows a pronounced loss of hardness after ETO/thermal-vacuum treatment; compressive strength is lost after ETO and thermal-vacuum (TVE) treatment; compression set is little changed after ETO treatment, decreased after TVE exposure and greatly increased after the ETO-TVE combination. RTV-615 displays a gain in compressive strength after TVE and ETO-TVE exposures and a low compression set after all exposures. RTV-40 and RTV-511 are not too much affected by the various exposures. Little change in electrical properties was observed for any of the samples.

It was observed that RTV-602 samples which had been exposed to the ETO cycles apparently released gases during the subsequent exposures to the thermal-vacuum environment (see Figure 4), as indicated by "holes" or "gas pockets" in the samples. Thus, these samples were examined by infrared spectrophotometry and mass specroscopy in an effort to detect any differences in structure or volatilized material.

The infrared spectra for the control sample and the three exposed samples revealed no differences in characteristic features nor any additional features.

Pieces of the samples were cut away from the surface (about 1/4" x 1/4" x 1/2") for mass spectrometric examination. They were placed in a sample holder which was fastened directly to the 3-liter reservoir of a standard inlet system. The sample holder was evacuated at room temperature and immediately brought to 125° C; the vapors were collected in the 3-liter reservoir until sufficient sample pressure was available for scanning.

It is interesting to note that even after 500 hours of exposure to an environment of 135° C and 10^{-6} torr, the TVE sample was still releasing sufficient substances (VCM) at 125° C in vacuo for mass spectrometric study. Since the original sample was about 1" thick and 2" in diameter, it can be re-affirmed that thermal-vacuum outgassing cannot be recommended for thick materials for spacecraft use.

The results of the mass spectroscopic determinations are summarized in Table 30, but they are not simply interpreted. Low-molecular-weight silicones and cyclic siloxanes have been observed in the vapors from all silicones examined thus far, but the presence of trimethyl silanol (used generally as a cross-linker for silicone resins) is unusual and might be taken as chemical evidence of the breakage of linkages. Values are given as estimated mol-ratios of the detected substances.

Tapes (Tables 24-26). - Of the half-dozen Mystik tapes examined, the general trend is toward loss in dimension, loss in weight (comparable to micro-VCM screening data), and general loss in peel strength. Mystik 7452 incurs the least weight loss, no dimensional change, and the greatest increase in peel strength after TVE or ETO-TVE, thus appearing superior to other tapes which displayed greater peel strength in the as-received condition. This data correlates well with the candidacy selection by micro-VCM determinations (0.37% wt-loss, 0.04% VCM), the fact that macro-VCM determinations indicate an apparent decrease with time of an already small VCM value, and the identification of volatile substances as plasticizers (or base materials) which may be polymerizing with heat or can be pumped away with time if condensed on a 25° C surface.

Tie Cord/Lacing Tape (Tables 27-29). - Neither of the two tapes tested at this time show as good performance as Temp-Lace 256H (fluorocarbon) reported in Interim Report No. 3.

FUTURE WORK

Micro- and macro-VCM determinations and identification of volatilized substances will be carried out on a continuing basis.

Series III in the comprehensive polymer test program will be initiated.

It is anticipated that preparation for long-term storage runs of qualified materials will be completed during the next working period.

ERRATA

Monthly Report No. 32 (February 15, 1967)

Page 5, Table II:

Change Electrofilm 2396, Postcured 16 hr/190° C
to Postcured 16 hr/205° C

Page 6, Table III:

Change Eccocoat PH-7, Cured 2 hr/50° C
to Cured 2 hr/150° C

Page 7, Table V:

Change column 2 to Wt-% VCM, Copper Discs
and column 3 to Wt-% VCM, Salt Flats

Table 1

Micro-VCM Determinations: Adhesives

(24 hr at 125° C and 10^{-6} torr)
(VCM collector plates at 25° C)

Material	Mfr.[1]	Treatment	Total Wt. Loss, %	VCM, wt-%
Epoxy-nitrile/nylon				
FM-61	ACB	Cured 1 hr/175° C	0.68	0.21
Epoxy-phenolic/ Al-glass				
HT-424	ACB	Cured 30 min/165° C	0.83	0.17
HT-424	ACB	Cured 2 hr/165° C	0.65	0.16
Epoxy, modified				
Narmco-328	WCN	Cured 90 min/165° C	0.12	0.10
Narmco-329	WCN	Cured 90 min/165° C	0.26	0.08

[1] ACB, American Cyanamid Company, Bloomingdale Division
WCN, Whittaker Corporation, Narmco Division

Table 2

Micro-VCM Determinations: Sleeving;
Effect of Postcures

(24 hr at 125° C and 10^{-6} torr)
(VCM collector plates at 25° C)

Material	Mfr.[1]	Treatment[2]	Total Wt. Loss, %	VCM, wt-%
Glass fiber +				
Ben-Har Pyrosleeve ST	BHM	As received	0.20	0.23
		Postcured 24 hr/150° C	0.13	0.11
Acrylic-glass fiber				
Ben-Har 263 FC-3	BHM	As received	0.54	0.32
Ben-Har Acryl A FA-1	BHM	As received	0.49	0.05
		Postcured 24 hr/150° C	0.22	0.05
Silicone-glass fiber				
Ben-Har 1062 HA-1	BHM	As received	0.31	0.23
		Postcured 24 hr/150° C	0.29	0.13
Ben-Har 1151 HA-1	BHM	As received	0.57	0.35
		Postcured 24 hr/150° C	0.42	0.24

[1] BHM, Bentley-Harris Manufacturing Company

[2] Results for all materials postcured 24 hr/150° C were reported in Interim Report No. 3, December 1966, and are reproduced here for comparison.

Table 3

Micro-VCM Determinations: Hardware and Structural;
Waxes for Spacecraft IR Use

(24 hr at 70° C and 10^{-6} torr)
(VCM collector plates at 25° C)

Material[1]	Mfr.[2]	Total Wt. Loss, %	VCM, wt-%
Montan Wax (Riebeck Romonta)	SAC	2.44	0.56
Carnauba Wax (Parnahya Grade)	SAC	0.88	0.76
Type F Hoechst Ester Wax (from Montan Wax)	AHC	5.47	2.98
Type F Hoechst Ester Wax (De-resinified)	AHC	4.47	2.60
Type KSS Hoechst Ester Wax (from Montan Wax)	AHC	1.21	0.13
Type KSS Hoechst Ester Wax (De-resinified)	AHC	1.08	0.11
Type L Hoechst Acid Wax (from Montan Wax)	AHC	1.97	0.36
Type L Hoechst Acid Wax (De-resinified)	AHC	2.07	0.37

[1] All waxes used as received.

[2] SAC, Strohmeyer & Arpe Company
AHC, American Hoechst Corporation

Table 4

Comparison of VCM Pick-Up on
Optical Salt Flats vs Copper Plates

(24 hr at 125° C and 10^{-6} torr)
(VCM collectors at 25° C)

Sample	Wt-% VCM on Copper Plate	Wt-% VCM on Salt Flat
Ben-Har Acryl A FA-1	0.05	0.03
Ben-Har Pyrosleeve ST	0.23	0.13
Ben-Har 263 FC-3	0.32	0.38
Ben-Har 1062 HA-1	0.23	0.12
Ben-Har 1151 HA-1	0.35	0.33
SE-555 (Red)	0.53	0.55

Table 5

Infrared Absorbance vs Weight of VCM
From Two Different Types of Silicone Effluents
(Preliminary Data)

Material	Wt. VCM, micrograms	IR Absorbance at 7.95 microns
Silicone "A"		
Ben-Har 1062 HA-1	140	0.130
	126	0.122
Ben-Har 1151 HA-1	291	0.185
	291	0.185
Silicone "B"		
SE-555 (Red)	700	0.315
	756	0.323
SR-220	400	0.150

Table 6

Macro-VCM Determinations: Tape and Temperature Control Coating

Material / Polymer Type	Property	Hours of Exposure at 125° C and 10^{-6} torr			
		24	48	96	330
Mystik 7452[1]					
Rubber-resin-aluminum	Wt. loss, %	0.15	0.18	0.18	0.19
	VCM, wt-%	0.06	0.03	0.05	0.03
Velvet Black 101-C10[2]					
Alkyd, modified	Wt. loss, %	0.84	0.70	1.01	1.38
	VCM, wt-%	0.10	0.09	0.14	0.13

[1] As received; dimensions: 0.5" x 48" x 0.004"

[2] Applied to 3-ft lengths of 18-ga copper wire and cured 168 hr/110°C

Table 7

Mass Spectrometric Analysis in Situ of Materials Volatilized at 125° C and 10^{-6} torr

Material	Major Component of Vaporized Substances	Minor Components
Velvet Black 101-C10	dioctylphthalate	--sebacate
Mystik 7452	glycol-benzoate; mono-ester of phthalic acid	toluene; water; dioctylphthalate

Table 8

Polymeric Products Examined in the Comprehensive Test Program (II)

Material	Use[1]	Polymer Type	Mfr.[2]	Treatment[3]
Adhesive 4684/RC805	AD	Polyester	DUP	Cured 0.5 hr/25° C @ 25 psi
Adhesive 46951	AD	Polyester	DUP	Cured 0.5 hr/25° C @ 25 psi
Eccobond 55/9	AD	Epoxy	EMC	Cured 4 hr/25° C + 1 hr/95° C @ 25 psi
Eccobond 104 A/B	AD	Epoxy	EMC	Cured 2 hr/95° C @ 25 psi
Epon 828/Versamid 125	AD	Epoxy	SAC	Cured 1 hr/65° C + 1 hr/95° C
RTV-40/T-12; primer SS-4004	AD	Silicone	GES	Primer cured 1 hr/75° C; RTV cured 1 hr/65° C + 1 hr/95° C
Ecco CP6/R-6	PC	Polyurethane	EMC	Cured 3 hr/105° C
Eccocoat EP-3 A/B	PC	Polyurethane	EMC	Cured 1 hr/120° C
Eccogel 1265 A/B	PC	Epoxy	EMC	Cured 1 hr/25° C + 2 hr/95° C + 3 hr/150° C
Stycast CPC-41 A/B	PC	Polyurethane	EMC	Cured 16 hr/95° C
Stycast 1269 A/B	PC	Epoxy	EMC	Cured 16 hr/100° C
Stycast 2741/15	PC	Epoxy	EMC	Cured 0.5 hr/70° C
RTV-40/T-12	SE	Silicone	GES	Cured 1 hr/65° C + 1 hr/95° C
RTV-511/T-12	SE	Silicone	GES	Cured 1 hr/65° C + 1 hr/95° C
RTV-602/13	SE	Silicone	GES	Cured 1 hr/65° C + 1 hr/95° C
RTV-615 A/B	SE	Silicone	GES	Cured 1 hr/65° C + 1 hr/95° C

Table 8 (concluded)

Butyl EX-1090	SG	Isobutylene/isoprene	SIS	Used as received
Butyl EX-1091	SG	Isobutylene/isoprene	SIS	Used as received
Butyl EX-1092	SG	Isobutylene/isoprene	SIS	Used as received
Butyl-805-70	SG	Isobutylene/isoprene	SIS	Used as received
SE-555 (Red)	SG	Silicone	GES	Used as received
Mystik 7020	TP	Rubber-resin/glass	BCM	Used as received
Mystik 7300	TP	Polyester-silicone	BCM	Used as received
Mystil 7352	TP	Polyester	BCM	Used as received
Mystik 7452	TP	Rubber resin-aluminum	BCM	Used as received
Mystik 7455	TP	Rubber resin-glass-Al	BCM	Used as received
Mystik 7503	TP	Fluorocarbon-silicone	BCM	Used as received
Nomex 722S	TC	Polyamide	GBE	Used as received
Stur-D-Lace H-18DH	TC	Polyester	GBE	Used as received
Eccofoam SH	HS	Polyurethane	EMC	Used as received

[1] AD, adhesives; PC, protective coatings; SE, sealants; SG, seals and gaskets; TP, tapes; TC, tie cord/lacing tapes; HS, hardware and structural.

[2] DUP, E. I. du Pont de Nemours and Company, Plastics Department
EMC, Emerson and Cuming, In c.
SAC, Shell Chemical Company, Adhesives Department
GES, General Electric Company, Silicone Products Department
SIS, Sargent Industries, Stillman Rubber Division
BCM, The Borden Chemical Company, Mystik Tape, Inc.
GBE, Gudebrod Brothers Silk Company, Inc., Electronics Division

[3] All protective coatings (PC) and sealants (SE) de-gassed 15 minutes at 23 torr prior to curing.

Table 9

Effects of Decontamination Cycles on Adhesives
(Six cycles of humidified ETO-Freon for 30 hr at 50° C)

Material	Weight Change, %	Adhesion Shear, psi	
		Control	Test
Adhesive 4684/RC-805	+1.98	1627	1066
Adhesive 46951	+0.66	962	532
Eccobond 55/9	+0.23	4450	4120
Eccobond 104 A/B	+0.29	1462	1315
Epon 828/Versamid 125	+3.15	2482	2242
RTV-40/T-12: Primer SS-4004	-0.21	592	480

Table 10

Effects of Thermal-Vacuum Environment on Adhesives
(500 hr at 135° C and 10^{-6} torr)

Material	Weight Change, %	Adhesion Shear, psi	
		Control	Test
Adhesive 4684/RC-805	-2.90	1627	1500
Adhesive 46951	temperature	service limit	exceeded
Eccobond 55/9	-0.14	4450	4400
Eccobond 104 A/B	-0.17	1462	1770
Epon 828/Versamid 125	-0.36	2482	3180
RTV 40/T-12: Primer SS-4004	-1.71	592	568

Table 11

Effects of Decontamination Cycles plus Thermal-Vacuum Environment on Adhesives

Material	Weight Change, %	Adhesion Shear, psi	
		Control	Test
Adhesive 4684/RC-805	-3.15	1627	1554
Adhesive 46951	temperature	service limit	exceeded
Eccobond 55/9	-0.07	4450	4040
Eccobond 104 A/B	+0.02	1462	1670
Epon 828/Versamid 125	+0.67	2482	3090
RTV-40/T-12: Primer SS-4004	-1.84	592	452

Table 12

Effects of Decontamination Cycles on Foam Material
(Six cycles of humidified ETO-Freon for 30 hr at 50° C)

Material	Dimensional Change, %	Weight Change, %	Compression Set, %	Compressive Strength, psi at 5%	
				Control	Test
Eccofoam SH	Dia., n. c. L, -0.30	+0.78	96.83	211	244

Table 13

Effects of Thermal-Vacuum Environment on Foam Material
(500 hr at 135° C and 10^{-6} torr)

Material	Dimensional Change, %	Weight Change, %	Compression Set, %	Compressive Strength, psi at 5%	
				Control	Test
Eccofoam SH	Dia., n. c. L, +0.20	-1.09	101.56	211	206

Table 14

Effects of Decontamination Cycles plus Thermal-Vacuum Environment on Foam Material

Material	Dimensional Change, %	Weight Change, %	Compression Set, %	Compressive Strength, psi at 5%	
				Control	Test
Eccofoam SH	Dia., n. c. L, +1.00	-0.93	101.87	211	206

Table 15

Effects of Decontamination Cycles on Protective Coatings
(Six cycles of humidified ETO-Freon for 30 hr at 50°C)

Material	Mechanical Properties				Electrical Properties				
	Dimensional Change, %	Weight Change, %	Adhesion Shear, psi		Frequency, MHz	Dielectric Constant		Dissipation Factor	
			Control	Test		Control	Test	Control	Test
Ecco CP6/R-6	Dia., n. c. L, n. c.	-0.08	953	592	1 15 25 35 50	4.64 4.18 4.18 4.01 4.01	4.66 4.28 4.17 4.09 3.96	0.019 0.020 0.020 0.019 0.025	0.022 0.023 0.023 0.018 0.017
Eccocoat EP-3 A/B	Dia., n. c. L, n. c.	+1.87	251	154	1 15 25 35 50	3.45 3.41 3.25 3.30 3.20	3.84 3.66 3.59 3.53 3.50	0.008 0.006 0.009 0.008 0.007	0.014 0.013 0.012 0.020 0.009
Eccogel 1265 A/B	Dia., +0.25 L, n. c.	+0.96	190	206	1 15 25 35 50	4.85 4.10 4.01 3.92 3.81	4.93 4.15 4.02 3.94 3.86	0.055 0.042 0.038 0.034 0.021	0.001 0.043 0.040 0.035 0.044
Stycast CPC-41 A/B	Dia., +0.74 L, n. c.	+0.94	286	109	1 15 25 35 50	3.21 3.06 3.02 2.99 2.99	3.30 3.10 3.09 3.02 3.02	0.008 0.007 0.006 0.006 0.005	0.010 0.007 0.006 0.014 0.010
Stycast 1269 A/B	Dia., +0.76 L, +0.84	+2.41	4130	3386	1 15 25 35 50	3.84 3.69 3.61 3.62 3.56	3.52 3.38 3.38 3.28 3.26	0.006 0.010 0.014 0.011 0.009	0.006 0.007 0.007 0.006 0.009
Stycast 2741/15	Dia., -6.50 L, +8.91	+25.10	1151	588	1 15 25 35 50	3.68 3.33 3.28 3.28 3.25	6.74 5.21 4.94 4.94 4.77	0.021 0.012 0.011 0.010 0.012	0.089 0.054 0.049 0.045 0.048

Table 16

Effects of Thermal-Vacuum Environment on Protective Coatings
(500 hr at 135° C and 10^{-6} torr)

Material	Mechanical Properties				Electrical Properties				
	Dimensional Change, %	Weight Change, %	Adhesion Shear, psi		Frequency MHz	Dielectric Constant		Dissipation Factor	
			Control	Test		Control	Test	Control	Test
Ecco CP6-R-6	Dia., -1.84 L, -1.65	-5.14	953	1380	1 15 25 35 50	4.64 4.18 4.18 4.01 4.01	4.82 4.37 4.33 4.32 4.17	0.019 0.020 0.020 0.019 0.025	0.019 0.018 0.018 0.021 0.027
Eccocoat EP-3 A/B	Dia., -1.15 L, -1.01	-4.52	251	509	1 15 25 35 50	3.45 3.41 3.25 3.30 3.20	3.49 3.44 3.35 3.30 3.30	0.008 0.006 0.009 0.008 0.007	0.008 0.009 0.009 0.008 0.005
Eccogel 1265 A/B	Dia., -0.30 L, n. c.	-1.06	190	382	1 15 25 35 50	4.85 4.10 4.01 3.92 3.81	4.73 3.96 3.94 3.81 3.76	0.055 0.042 0.038 0.034 0.021	0.051 0.040 0.035 0.016 0.028
Stycast CPC-41 A/B	Dia., n. c. L, -0.15	-0.61	286	254	1 15 25 35 50	3.21 3.06 3.02 2.99 2.99	3.20 3.10 3.06 3.03 3.03	0.008 0.007 0.006 0.006 0.005	0.008 0.006 0.006 0.006 0.004
Stycast 1209 A/B	Dia., -0.24 L, -0.87	-0.49	4130	3960	1 15 25 35 50	3.84 3.69 3.61 3.62 3.56	3.43 3.28 3.20 3.25 3.25	0.006 0.010 0.014 0.011 0.009	0.005 0.006 0.005 0.004 0.001
Stycast 2741/15	Dia., -2.50 L, -1.98	-7.17	1151	2176	1 15 25 35 50	3.68 3.33 3.28 3.28 3.25	3.68 3.41 3.33 3.33 3.33	0.021 0.012 0.011 0.010 0.012	0.013 0.009 0.008 0.008 0.003

Table 17
Effects of Decontamination Cycles plus Thermal-Vacuum Environment on Protective Coatings

Material	Mechanical Properties				Electrical Properties				
	Dimensional Change, %	Weight Change, %	Adhesion Shear, psi		Frequency MHz	Dielectric Constant		Dissipation Factor	
			Control	Test		Control	Test	Control	Test
Ecco CP6/R-6	Dia., -1.74 L, -1.54	-5.95	953	2062	1 15 25 35 50	4.64 4.18 4.18 4.01 4.01	4.76 4.36 4.22 4.16 4.14	0.019 0.020 0.020 0.019 0.025	0.018 0.018 0.017 0.019 0.025
Eccocoat EP-3 A/B	Dia., -1.77 L, -1.98	-4.49	251	450	1 15 25 35 50	3.45 3.41 3.25 3.30 3.20	3.57 3.34 3.31 3.31 3.31	0.008 0.006 0.009 0.008 0.007	0.006 0.007 0.009 0.009 0.002
Eccogel 1265 A/B	Dia., -0.36 L, n. c.	-2.46	190	606	1 15 25 35 50	4.85 4.10 4.01 3.92 3.81	4.66 4.02 3.94 3.78 3.70	0.055 0.042 0.038 0.034 0.021	0.047 0.042 0.034 0.030 0.027
Stycast CPC-41 A/B	Dia., -0.15 L, -0.78	-1.12	286	380	1 15 25 35 50	3.21 3.06 3.02 2.99 2.99	3.17 3.06 3.02 3.01 3.01	0.008 0.007 0.006 0.006 0.005	0.008 0.005 0.005 0.006 0.005
Stycast 1269 A/B	Dia., +0.24 L, +0.75	+0.70	4130	3750	1 15 25 35 50	3.84 3.69 3.61 3.62 3.56	3.39 3.14 3.24 3.20 3.20	0.006 0.010 0.014 0.011 0.009	0.005 0.005 0.005 0.003 0.005
Stycast 2741/15	sample degraded deg.	s.	1151	1942	1 15 25 35 50	3.68 3.33 3.28 3.28 3.25	s. deg.	0.021 0.012 0.011 0.010 0.012	s. deg.

Table 18

Effects of Decontamination Cycles on Sealants
(Six cycles of humidified ETO-Freon for 30 hr at 50° C)

Material	Mechanical Properties						
	Dimensional Change, %	Weight Change, %	Shore Hardness		Compressive Strength, psi at 10%		Compression Set, %
			Control	Test	Control	Test	
RTV-40/T-12	L, n. c. ; W, n. c.	-0.21	58.0	60.3	47.4	48.9	95.69
RTV-511/T-12	L, n. c. ; W, -0.49	-1.00	50.2	50.5	31.7	29.8	74.42
RTV-602/13	L, n. c. ; W, -0.09	-0.44	30.8	28.5	17.4	13.0	108.83
RTV-615 A/B	L, -0.20; W, n. c.	+0.05	60.8	58.8	33.5	29.5	15.25

Electrical Properties

Material	Frequency, MHz	Dielectric Constant		Dissipation Factor	
		Control	Test	Control	Test
RTV-40/T-12	1	3.19	3.40	0.0026	0.0009
	15	3.19	3.39	0.0012	0.0009
	25	3.19	3.38	0.0009	0.0011
	35	3.19	3.37	<0.0001	0.0010
	50	3.19	3.19	<0.0001	0.0008
RTV-511/T-12	1	3.62	3.59	0.0023	0.0009
	15	3.64	3.59	0.0015	0.0005
	25	3.63	3.57	0.0015	0.0002
	35	3.62	3.57	0.0043	0.0009
	50	3.52	3.70	<0.0001	0.0012
RTV-602/13	1	2.92	2.91	0.0010	0.0009
	15	2.88	2.92	0.0010	<0.0001
	25	2.88	2.92	<0.0001	<0.0001
	35	2.88	2.92	<0.0001	<0.0001
	50	2.88	2.92	<0.0001	<0.0001
RTV-615 A/B	1	2.89	2.98	0.0003	<0.0001
	15	2.88	2.96	<0.0001	<0.0001
	25	2.88	2.97	<0.0001	<0.0001
	35	2.88	2.97	<0.0001	<0.0001
	50	2.88	2.97	<0.0001	<0.0001

Table 19

Effects of Thermal-Vacuum Environment on Sealants
(500 hr at 135° C and 10^{-6} torr)

Material	Mechanical Properties						
	Dimensional Change, %	Weight Change, %	Shore Hardness		Compressive Strength, psi at 10%		Compression Set, %
			Control	Test	Control	Test	
RTV-40/T-12	L, -1.20; W, -0.50	-1.71	58.0	59.2	47.4	52.8	102.63
RTV-511/T-12	L, -2.21; W, -1.75	-4.96	50.2	51.3	31.7	37.2	101.72
RTV-602/13	L, -0.40; W, -0.86	-2.31	30.8	29.0	17.4	13.3	87.27
RTV-615 A/B	L, -1.18; W, -0.63	-1.72	60.8	60.9	33.5	41.8	75.42

Electrical Properties

Material	Frequency, MHz	Dielectric Constant		Dissipation Factor	
		Control	Test	Control	Test
RTV-40/T-12	1	3.19	3.41	0.0026	0.0011
	15	3.19	3.41	0.0012	0.0007
	25	3.19	3.39	0.0009	0.0006
	35	3.19	3.40	<0.0001	0.0017
	50	3.19	3.39	<0.0001	0.0004
RTV-511/T-12	1	3.62	3.51	0.0033	0.0028
	15	3.64	3.54	0.0015	0.0014
	25	3.63	3.51	0.0015	0.0031
	35	3.62	3.51	0.0043	<0.0001
	50	3.52	3.51	< 0.0001	<0.0001
RTV-602/13	1	2.92	3.03	0.0010	0.0007
	15	2.88	3.10	0.0010	<0.0001
	25	2.88	3.04	<0.0001	<0.0001
	35	2.88	3.06	<0.0001	<0.0001
	50	2.88	3.06	<0.0001	<0.0001
RTV-615 A/B	1	2.89	2.95	0.0003	0.0002
	15	2.88	2.97	<0.0001	0.0006
	25	2.88	2.95	<0.0001	0.0003
	35	2.88	2.94	<0.0001	<0.0001
	50	2.88	2.95	<0.0001	<0.0001

Table 20

Effects of Decontamination Cycles plus Thermal-Vacuum Environment on Sealants

Material	Mechanical Properties						
	Dimensional Change, %	Weight Change, %	Shore Hardness		Compressive Strength, psi at 10%		Compression Set, %
			Control	Test	Control	Test	
RTV-40/T-12	L, -1.02; W, 0.00	-1.84	58.0	60.7	47.4	51.8	107.76
RTV-511/T-12	L, -2.10; W, -2.25	-5.37	50.2	51.2	31.7	34.6	113.56
RTV-602/13	L, -2.19; W, -1.04	-4.97	30.8	16.8	17.4	--	142.73
RTV-615 A/B	L, -0.40; W, -9.50	-1.56	60.8	61.4	33.5	51.8	76.92

Electrical Properties

Material	Frequency, MHz	Dielectric Constant		Dissipation Factor	
		Control	Test	Control	Test
RTV-40/T-12	1	3.19	3.43	0.0026	0.0013
	15	3.19	3.42	0.0012	0.0009
	25	3.19	3.38	0.0009	0.0008
	35	3.19	3.38	<0.0001	0.0008
	50	3.19	3.38	<0.0001	0.0005
RTV-511/T-12	1	3.62	3.61	0.0023	0.0002
	15	3.64	3.63	0.0015	<0.0001
	25	3.63	3.61	0.0015	0.0010
	35	3.62	3.61	0.0043	0.0020
	50	3.52	3.61	<0.0001	<0.0001
RTV-602/13	1	2.92	3.08	0.0010	0.0004
	15	2.88	3.19	0.0010	0.0002
	25	2.88	3.11	<0.0001	0.0003
	35	2.88	3.13	<0.0001	<0.0001
	50	2.88	3.10	<0.0001	<0.0001
RTV 615 A/B	1	2.89	2.97	0.0003	<0.0001
	15	2.88	2.97	<0.0001	0.0003
	25	2.88	2.97	<0.0001	<0.0001
	35	2.88	2.98	<0.0001	<0.0001
	50	2.88	2.98	<0.0001	<0.0001

Table 21

Effects of Decontamination Cycles on Seal and Gasket Materials
(Six cycles of humidified ETO-Freon for 30 hr at 50° C)

Material	Dimensional Change, %	Weight Change, %	Shore Hardness		Tensile, psi		Elongation at Break, %	
			Control	Test	Control	Test	Control	Test
Butyl EX-1090	L, +0.15; W, +0.10	+0.72	70.7	72.2	2240	2180	550	500
Butyl EX-1091	L, +0.32; W, +0.67	+1.14	71.0	71.7	1800	1610	380	325
Butyl EX-1092	L, +0.17; W, +0.05	+0.76	76.2	76.4	1880	1630	210	182
Butyl 805-70	L, +0.41; W, +0.36	+1.22	77.2	76.9	1120	1350	295	325
SE-555 (Red)	L, +0.04; W, +0.52	+0.12	70.6	69.8	1080	1160	500	488

Table 22

Effects of Thermal-Vacuum Environment on Seal and Gasket Materials
(500 hr at 135° C and 10^{-6} torr)

Material	Dimensional Change, %	Weight Change, %	Shore Hardness		Tensile, psi		Elongation at Break, %	
			Control	Test	Control	Test	Control	Test
Butyl EX-1090	L, -0.39; W, -0.58	-1.57	70.7	86.6	2240	1710	550	129
Butyl EX-1091	L, -0.50; W, n. c.	-1.49	71.0	79.8	1800	1840	380	200
Butyl EX-1092	L, -0.96; W, -0.56	-2.11	76.2	85.7	1880	1380	210	78
Butyl 805-70	L, -1.00; W, -1.07	-2.42	77.2	79.9	1120	1100	295	208
SE-555 (Red)	L, -0.08; W, -0.20	-0.76	70.6	69.6	1080	1440	500	512

Table 23

Effects of Decontamination Cycles plus Thermal-Vacuum Environment
on Seal and Gasket Materials

Material	Dimensional Change, %	Weight Change, %	Shore Hardness		Tensile, psi		Elongation at Break, %	
			Control	Test	Control	Test	Control	Test
Butyl EX-1090	L, -0.63; W, +0.94	-2.20	70.7	84.6	2240	1970	550	170
Butyl EX-1091	L, -0.74; W, +0.10	-1.63	71.0	79.8	1800	1840	380	200
Butyl EX-1092	L, +0.86; W, -0.20	-2.93	76.2	84.5	1880	1510	210	91
Butyl 805-70	L, -1.44; W, -0.56	-2.22	77.2	80.1	1120	1350	295	238
SE-555 (Red)	L, n. c.; W, -0.56	-0.75	70.6	70.0	1080	1630	500	475

Table 24

Effects of Decontamination Cycles on Tapes
(Six cycles of humidified ETO-Freon for 30 hr at 50° C)

Material	Dimensional Change, %	Weight Change, %	T-Peel Test, lb/in-width	
			Control	Test
Mystik 7300	-0.37	+1.24	3.18	3.64
Mystik 7352	-0.11	+0.58	2.10	1.68
Mystik 7452	n. c.	+0.33	2.10	4.86
Mystik 7455	-0.10	+0.04	3.74	3.72
Mystik 7503	-0.17	+0.02	2.70	2.98
Mystik 7020	n. c.	+2.64	5.61	6.10

Table 25

Effects of Thermal-Vacuum Environment on Tapes
(500 hr at 135° C and 10^{-6} torr)

Material	Dimensional Change, %	Weight Change, %	T-Peel Test, lb/in-width	
			Control	Test
Mystik 7300	-2.44	-1.44	3.18	2.98
Mystik 7352	-1.24	-3.08	2.10	1.42
Mystik 7452	n. c.	-0.31	2.10	11.07
Mystik 7455	-0.71	-2.56	3.74	3.75
Mystik 7503	-0.71	-1.20	2.70	2.12
Mystik 7020	n. c.	-2.32	5.61	8.16

Table 26

Effects of Decontamination Cycles plus Thermal-Vacuum Environment on Tapes

Material	Dimensional Change, %	Weight Change, %	T-Peel Test lb/in-width	
			Control	Test
Mystik 7300	-2.36	-1.94	3.18	1.86
Mystik 7352	-1.19	-2.72	2.10	1.90
Mystik 7452	n. c.	-0.34	2.10	9.01
Mystik 7455	n. c.	-2.57	3.74	3.55
Mystik 7503	-1.04	-0.92	2.70	2.38
Mystik 7020	n. c.	-2.64	5.61	5.59

Table 27

Effects of Decontamination Cycles on Tie Cord/Lacing Tapes
(Six cycles of humidified ETO-Freon for 30 hrs at 50° C)

Material	Dimensional Change, %	Weight Change, %	Tensile, psi		Elongation at Break, %	
			Control	Test	Control	Test
Stur-D-Lace 18DH	L, +2.40	+1.35	32,000	39,000	<1	<1
Nomex 722	L, +3.50	+2.50	36,000	32,800	<1	<1

Table 28

Effects of Thermal-Vacuum Environment on Tie Cord/Lacing Tapes
(500 hr at 135° C and 10^{-6} torr)

Material	Dimensional Change, %	Weight Change %	Tensile, psi		Elongation at Break, %	
			Control	Test	Control	Test
Stur-D-Lace 18DH	L, -11.04	-1.45	32,000	34,100	<1	<1
Nomex 722	L, -0.21	-4.28	36,100	32,600	<1	<1

Table 29

Effects of Decontamination Cycles plus Thermal-Vacuum Environment on Tie Cord/Lacing Tapes

Material	Dimensional Change, %	Weight Change, %	Tensile, psi		Elongation at Break, %	
			Control	Test	Control	Test
Stur-D-Lace 18DH	L, -7.17	-1.39	32,000	38,000	<1	<1
Nomex 722	L, +3.29	-3.25	36,100	35,900	<1	<1

Table 30

Mass Spectrometric Analysis of Substances Released by RTV-602 at 125° C in Vacuo After Different Treatments

Component	Estimated Mol-Ratios			
	Control Sample	ETO* Exposure	ETO-TVE* Exposure	TVE* Exposure
Low-mol.-wt. silicones	2.7	5.3	4.3	1.2
Trimethyl silanol	1.0	1.0	1.0	1.0
Cyclic siloxanes	0.4	1.4	1.8	0.5

*ETO, six 30-hr cycles of humidified ETO-Freon at 50° C

TVE, 500 hours in thermal vacuum environment of 135° C and 10^{-6} torr

ETO-TVE, ETO plus TVE.

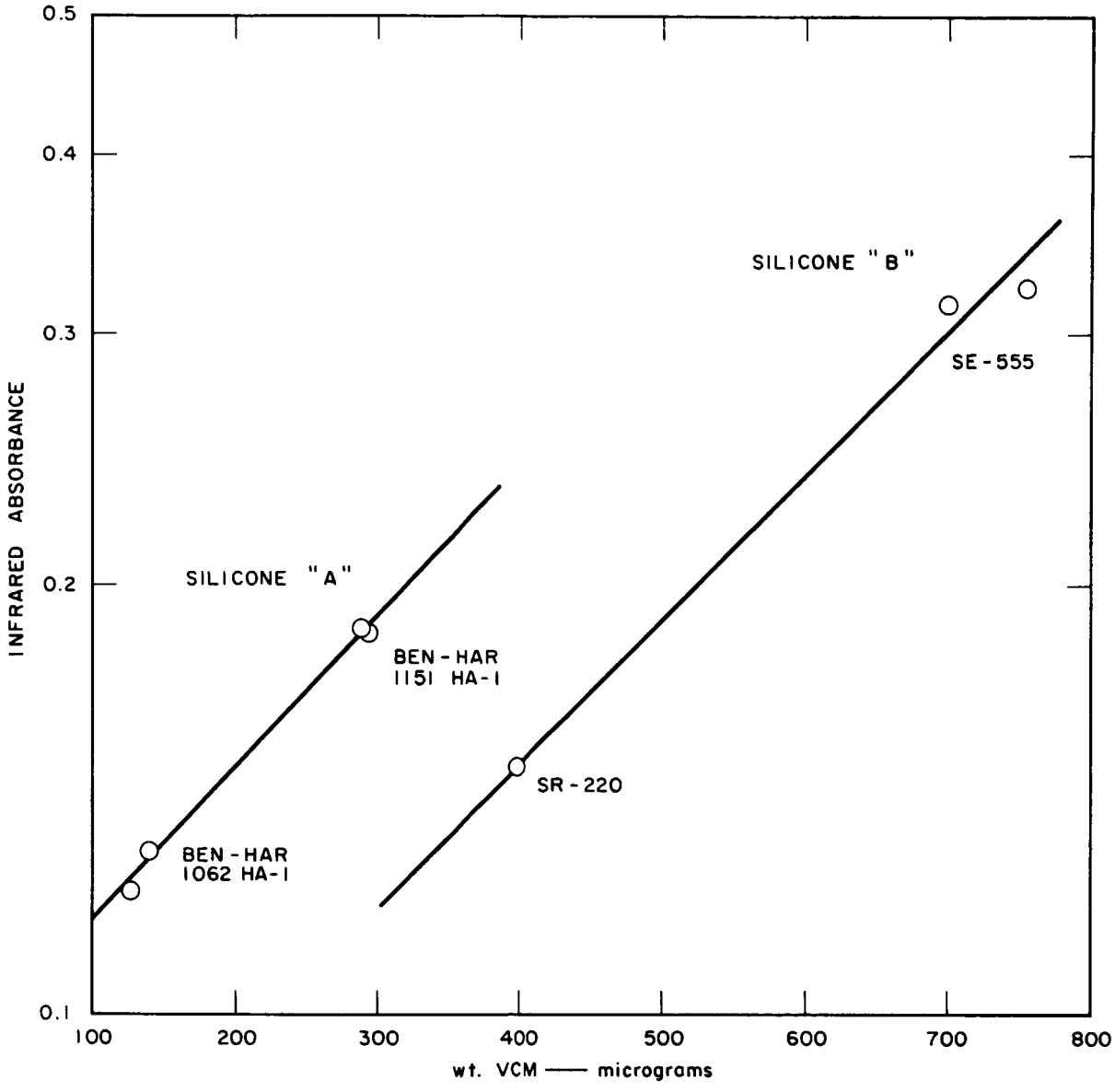


FIG. 1 INFRARED ABSORBANCE vs WEIGHT OF VCM FROM TWO DIFFERENT TYPES OF SILICONE EFFLUENTS (Preliminary Data)

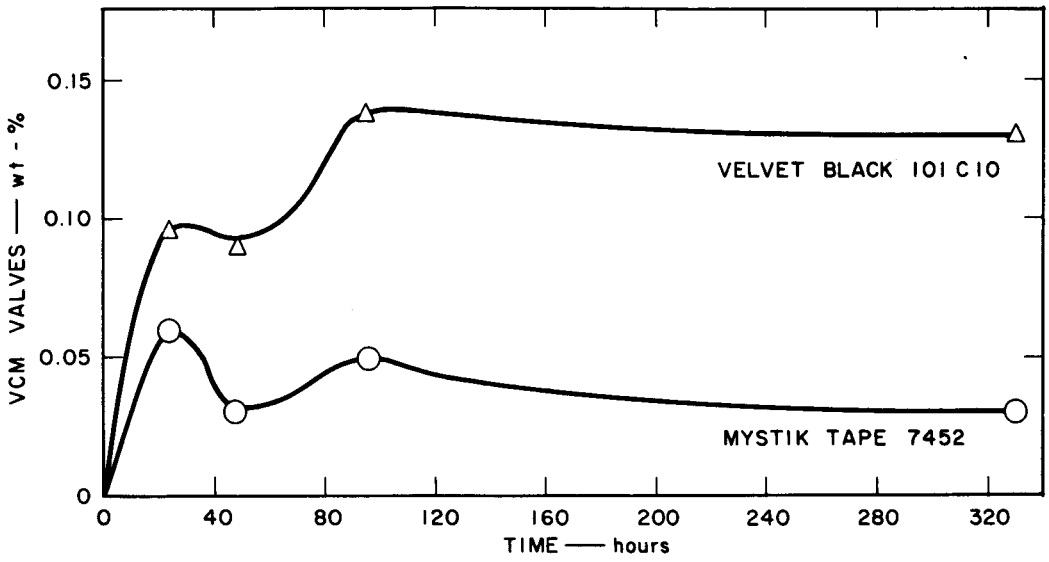


FIG. 2 VCM VALUES AT 125/25°C FOR A TAPE AND A TEMPERATURE-CONTROL COATING

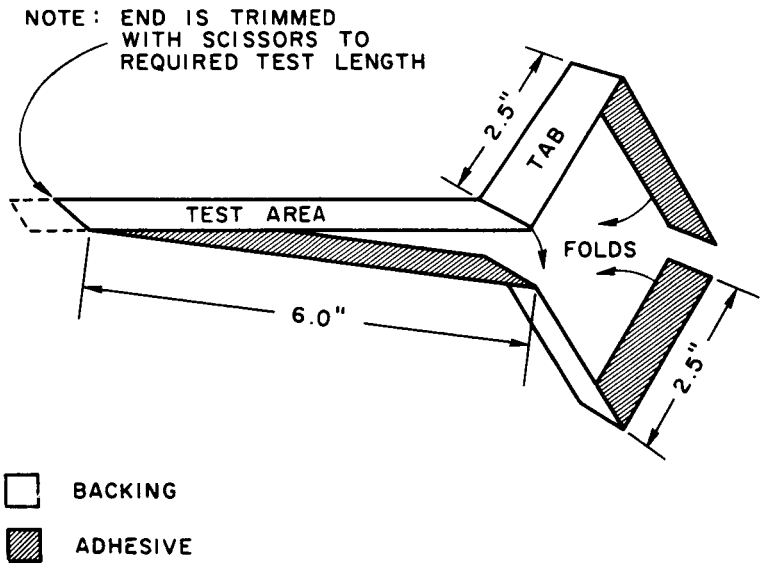
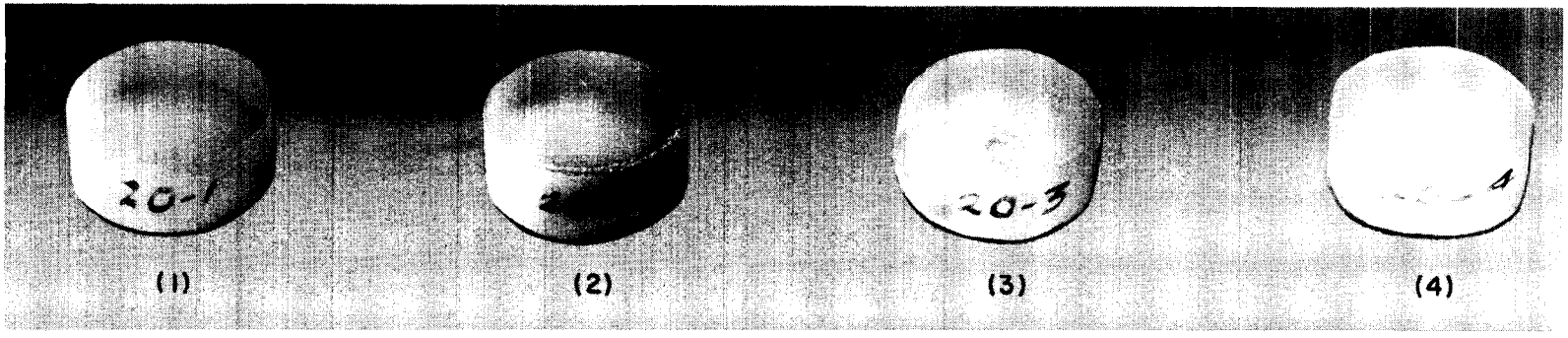


FIG. 3 SHOWING THE METHOD OF FOLDING TAPE AND INSULATION MATERIAL FOR T-PEEL TESTING



(1) CONTROL SAMPLE

(2) AFTER EXPOSURE TO HUMIDIFIED ETO-FREON ATMOSPHERE

(3) AFTER EXPOSURE TO ETO-FREON ATMOSPHERE PLUS EXPOSURE TO THERMAL-VACUUM ENVIRONMENT

(4) AFTER EXPOSURE TO THERMAL-VACUUM ENVIRONMENT ONLY

FIG. 4 APPEARANCE OF RTV-602/13 SAMPLES AFTER EXPOSURE TO DIFFERENT ENVIRONMENTS